Evolution and Religion:
From Conflict to Concert

The John Calvin McNair Lecture
on Science and Theology

Francisco J. Ayala

Evolution and Religion:
From Conflict to Concert

Francisco J. Ayala

St. Andrews University
Laurinburg, North Carolina

Copyright © 2011 by Francisco J. Ayala

St. Andrews University
1700 Dogwood Mile
Laurinburg, NC 28352
910/277-5555

About the McNair Lecture

The McNair Lecture was established by the 1857 will of John Calvin McNair, who asked that "the object of which lecture(s) shall be to show the mutual bearing of Science and Theology upon each other."

The lecture is currently hosted by St. Andrews University. The series was previously hosted by the University of North Carolina at Chapel Hill and included such noted speakers as Stephen J. Gould, John C. Polkinghorne, Ian G. Barbour, J. Robert Oppenheimer, Charles A. Coulson, and John Dewey.

Introduction

The argument from design has two parts. In one familiar form it asserts first that organisms evince to have been designed and second that only God could account for the design. The argument from design was advanced, in a variety of forms, in Classical Greece and early Christianity. Its most extensive formulation is due to William Paley in his *Natural Theology*. The eye—as well as all sorts of organs, organisms, and their interactions—manifests to be the outcome of design and not of chance; thus, it shows to have been created by God. In the 1990s, the design argument was revived in the United States by several authors. The flagellum used by bacteria for swimming and the immune system of mammals, as wel as some improbability calculations, were advanced as evidence of "intelligent design" on the grounds that chance processes could not account for the phenomena.

In *On The Origin of Species*, Darwin advaned a scientific explanation of the design of organisms. The adaptations of organisms are outcomes not of chance but of a process that, over time, causes the gradual accumulation of features beneficial to organisms, whenever these features increase the organisms' chances of surviving and reproducing. There is "design" in the living world: eyes are designed for seeing, wings for flying, and kidneys for regulating the composition of the blood. The design of organisms comes about not through intelligent design but by a natural process, which is creative through the interaction of chance and necessity.

Organisms are pervaded by imperfections, dysfunctions, cruelties, and even sadism. The theory of evolution accounts for these mishaps by natural selection, as the outcomes of natural processes, so that they need not be attributed to God's explicit design.

The Argument from Design

The argument from design to demonstrate the existence of God has been repeatedly used throughout the history of Christianity, but in different versions. The argument from design is a two-pronged argument. The first prong asserts that there is design in the universe. The second affirms that only God, an omnipotent and omniscient Creator, could account for the perfection and universality of the design.

The first prong comes, importantly, in at least two flavors. One refers to the order and harmony of the universe as a whole as, for example, in St. Augustine: "The world iteslf, by the perfect order of its changes and motions and by the great beauty of all things visible" (452-3) or St. Thomas Aquinas: "It is impossible for contrary and discordant things to fall into one harmonious order except under some guidance, assigning to each and all parts a tendency to a fixed end. But in the world we see things of different natures falling into harmonious order" (1905, 12). The second version refers to the living world, the intricate organized complexity of organisms as formulated, among others, by William Paley and the modern proponets of intelligent design, or ID.

The second prong of the argument from design has been formulated in at least three important versions. One forumlation of the Designer appears in Classical Greece, including Plato, who postulates the existence of a Demiurge, a creator of the universe's order, who is a universal and impersonal ordering principle rather than the personalized Judeo-Christian God. Plato's Demiurge is an orderer of the world who accounts for the world's rationality, but not necessarily for its creation. A second version is the familiar one of the Judeo-Christian God, as formulated by Paley and other Christian philosophers and theologians (e.g., Aquinas, Swinburne), who is a "person," the creator and steward of the universe, who creates a world from nothing and is omniscient, omnipotent, omnibenevolent, and provident for humans. Proponents of ID have in recent years formulated a third version of the second prong: an unidentified Designer who may account for the order and complexity of the universe, or who may simply intervene from time to time in the universe so as to design organisms and their parts, because the complexity of organisms, it is claimed, cannot be accounted for by natural processes. According to ID proponents, this intelligent designer could be, but need not be, God. It could be an alien from outer space or some other creature, such as a "time-traveling cell biologist" with amazing powers.

An elaborate formulation of the argument from design was *The Wisdom of God Manifested in the Works of Creation* by the English Clergyman and naturalist John Ray. Ray regarded as incontrovertible evidence of God's wisdom that all components of the universe—the stars and planets as well as all organisms—are so wisely contrived from the beginning and perfect in their operation. The "most convincing argument of the Existence of a Deity," writes Ray, "is the admirable Art and Wisdom that discovers itself in the Make of the Constitution, the Order and Disposition, the Ends and uses of all the parts and members of this stately fabric of Heaven and Earth" (33).

The design argument was advanced, in greater or lesser detail, by a number of authors in the seventeenth and eighteenth centuries (e.g., Arp, Klocker). John Ray's contemporary Henry More saw evidence of God's design in the succession of day and night and of the seasons: "I say that the Phenomena of Day and Night, Winter and Summer, Springtime and Harvest [...] are signs and tokens unto us that there is a God [...] things are so framed that they naturally imply a Principle of Wisdom and Counsel in the Author of them.

And if there be such an author of external Nature, there is a God" (38). Robert Hooke, a physicist and eventual Secretary of the Royal Society, formulated the watchmaker analogy: God has furnished each plant and animal "with all kinds of contrivances necessary for its own existence and propagation [...] as a Clock-maker might make a Set of Chimes to be part of a Clock" (124). This anaolgy—among others such as temples, palaces, and ships—was also used by Thomas Burnet in his *Sacred Theory of the Earth*, and it would become common among natural theologians of the time.

On the Continent, the Dutch philosopher and theologian Bernard Nieuwentijdt developed, at lenght, the argument from design in his three-volume treatise *The Religious Philosopher* where, in the Preface, he introduces the watchmaker analogy. Voltaire, like other philosophers of the enlightenment, accepted the argument from design. He asserted that, in the same way as the existence of a watch proves the existence of a watchmaker, the design and purpose evident in nature prove that the universe was created by a Supreme Intelligence (262-70).

The most elaborate formulation of the argument from design is William Paley's *Natural Theology*. Paley was an influential writer of works on Christian philosophy, ethics, and theology, such as *The Principles of Moral and Political Philosophy*, pubished in 1785, and *A View of the Evidences of Christianity*, published in 1794. With *Natural Theology*, Paley sought to update Ray's *Wisdom of God Manifested in the Works of the Creation*. But Paley could now carry the argument much further than Ray by taking advantage of one century of additional biological knowledge. Paley's keystone claim is that there "cannot be design without a designer; contrivance, without a contriver; order, without choice; [...] means suitable to an end, and executing their office in accomplishing that end, without the end ever having been contemplated" (15-6). *Natural Theology* is a sustained argument for the existence of God based on the obvious design of humans and their organs, as well as the design of all sorts of organisms, considered by themselves and in their relations to one another and to their environment. Paley's first analogical example in *Natural Theology* is the human eye. Early in Chapter Three, Paley points out that they eye and the telescope "are made upon the same principles; both being adjusted to the laws by which the transmission and refraction of rays of light are regulated" (20). Specificaly, there is a precise resemblance between the lenses of a telescope and "the humors of the eye" in their figure, their position, and the ability of converging the rays of light at a precise distance from the lens—or the retina, in the case of the eye.

Paley makes two remarkable observations, which enhance the complex and precise design of the eye. The first observation is that rays of light should be refracted by a more convex surface when transmitted through water than when passing out of air into the eye. Accordingly, "the eye of a fish, in that part of it called the crystalline lens, is much rounder than the eye of terrestrial animals. What plainer manifestation of design can there be in this difference? What could a mathematical instrument maker have done more to show his knowledge of [t]his principle [...]?" (20). The second remarkable observation made by Paley in support of his argument is dioptric distortion: "Pencils of light, in passing through glass lenses, are separated into different colors, thereby tinging the object, especially the edges of it, as if it were viewed through a prism. To correct this inconvenience [...] a sagacious optician [...observed] that in the eye the evil was cured by combining lenses composed of different substances, that is, of substances which possessed different refracting powers" (22-3). The telescope maker, accordingly, corrected the dioptric distortion "by imitating, in glasses made from different materials, the effects of the different humors through which the rays of light pass before they reach the bottom of the eye. Could this be in the eye without purpose, which suggested to the optician the only effectual means of attaining that purpose?" (23).

Natural Theology has chapters dedicated to the human frame, which displays a precise mechanical arrangement of bones, cartilage, and joints; to the circulation of the blood and the disposition of blood vessels; to the comparative anatomy of humans and animals; to the digestive tract, kidneys, urethra, and bladder; to the wings of birds and the fins of fish; and much more. For 352 pages, *Natural Theology* conveys Paley's expertise: extensive and accurate biological knowledge, as detailed and precise as was available in 1802. After detailing the precise organization and exquisite functionality of each biological entity, relationship, or process, Paley draws again and again the same conclusion: only an omniscient and omnipotent deity could account for these marvels of mechanical perfection, purpose, and functionality, and for the enormous diversity of inventions that they entail.

In 1829, nearly three decades after *Natural Theology*, Francis Henry Egerton, the eighth Earl of Bridgewater, bequeathed eight thousand pounds sterling with instructions to the Royal Society that it commission eight treatises that would promote natural theology by setting forth "The Power, Wisdom and Goodness of God as manifested in the Creation." Eight treatises were published in the 1830s, several of which artfully incorporate the best science of the time and had considerable influence on the public and among scientists. One additional treatise, never completed, was authored by the notable mathematician and pioneer in the field of calculating machines, Charles Babbage. In *The Ninth Bridgewa-*

ter Treatise: A Fragment, published in 1838, he seeks to show how mathematics may be used to bolster religious belief. One of the Bridgewater treatises, *The Hand, Its Mechanisms and Vital Endowments as Evincing Design*, was published by Sir Charles Bell in 1833. Bell was a distinguished anatomist and surgeon, famous for his neurological discoveries, who became professor of surgery in 1836 at the University of Edinburgh. William Buckland, Professor of Geology at Oxford University, notes in his 1836 *Genealogy and Mineralogy* the world distribution of coal and mineral ores and proceeds to point out that they had been deposited in a remote part, yet obviously with the forethought of serving the larger human populations that would come about much later. Another geologist, Hugh Miller, formulated in his 1858 *The Testimony of the Rocks* what I call the argument from beauty, which allows that it is not only the perfection of design but also the beauty of natural structures found in rock formations and in mountains and rivers that manifests the intervention of the creator.

The Problem of Evil

Christian scholars for centuries struggled with the problem of evil in the world. The Scottish philosopher David Hume set the problem succinctly with humble directness: "Is [God] willing to prevent evil, but not able? Then he is impotent. Is he able, but not willing? Then, he is malevolent. Is he both able and willing? Whence then evil?" (244). If the reasoning is valid, it would follow that God is not all-powerful or all-good. Christian theology accepts that evil exists, but denies the validity of the argument.

Traditional theology distinguishes three kinds of evil: first, moral evil or sin, the evil originated by human beings; second, pain and suffering as experience by human beings; and last, physical evil, such as floods, tornados, earthquakes, and the imperfections of all creatures.

Theology has a ready answer for the first two kinds of evil. Sin is a consequence of free will; the flip side of sin is virtue, also a consequence of free will. Christian theologians have expounded that if humans are to enter into a genuinely personal relationship with their maker, they must first experience some degree of freedom and autonomy. The eternal reward of heaven calls for a virtuous life as many Christians see it. Christian theology also provides a good accounting of human pain and suffering. To the extent that pain and suffering are caused by war, injustice, and other forms of human wrongdoing, they are also a consequence of free will; people choose to inflict harm on one another. On the flip side are good deeds by which people choose to alleviate human suffering.

What about earthquakes, storms, floods, droughts, and other physical catastrophes? Enter modern science into the theologian's reasoning. Physical events are built into the structure of the world itself. Since the seventeenth century, humans have known that the processes by which galaxies and stars come into existence, planets fom, continents move, weather and seasons change, and flood or earthquakes occur are natural ones, not events specifically designed by God for punishing or rewarding humans. The extreme violence of supernova explosions and the chaotic frenzy at galactic centers are outcomes of the laws of physics, not the design of a fearsome deity.

Alas, theodicy still encountered a seemingly insurmountable difficulty. If God is the designer of life, whence the lion's cruelty, the snake's poison, and the parasites that secure their existence only by destroying their hosts? Evolution came to the rescue. Jack Haught, a contemporary Roman Catholic theologian, has written of "Darwin's gift to theology." The

Protestant theologian Arthur Peacocke has referred to Darwin as the “disguised friend,” by quoting the earlier theologian Aubrey Moore, who in 1891 wrote that “Darwinism appeared, and, under the guise of a foe, did the work of a friend” (Peacocke 357). Haught and Peacocke are acknowledging the irony that the theory of evolution, which at first had seemed to remove the need for God in the world, now has convincingly removed the need to explain the world’s imperfections as failed outcomes of God’s design.

Indeed, a major burden was removed from the shoulders of believers when convincing evidence was advanced that the design of organisms need not be attributed to the immediate agency of the Creator, but rather is an outcome of natural processes. If we claim that organisms and their parts have been specifically designed by God, we have to account for the incompetent design of the human jaw, the narrowness of the birth canal, and our poorly-designed backbone, less than fittingly suited for walking upright. Modern proponents of ID would do well to acknowledge Darwin’s revolution and accept natural selection as the process that accounts for the design of organisms, as well as for the dysfunctions, oddities, cruelties, and sadism that pervade the world of life. Attributing these to specific agency by the Creator accounts to blasphemy.

One difficulty with attributing the design of organisms to the Creator is that imperfections and defects pervade the living world. Consider the human eye. The visual nerve fibers in the eye converge to form the optic nerve, which crosses the retina (in order to reach the brain) and thus creates a blind spot, a minor imperfection, but an imperfection of design nevertheless; squids and octopi do not have this defect. Did the Designer have a greater love for squids than for humans and thus exhibit greater care in designing their eyes than ours?

Defective design would seem incompatible with an omnipotent Intelligent Designer. Anticipating this criticism, Paley responded that “apparent blemishes [...] ought to be referred to some cause, though we be ignorant of it.” Modern ID proponents have made similar assertions. According to Michael Behe, “The argument from imperfections overlooks the possibility that the designer might have multiple motives, with engineering excellence oftentimes relegated to a secondary role [.... T]he reasons that a designer would or would not do anything are virtually impossible to know unless the designer tells you specifically what those reasons are.” The theory of ID is not good theology because it leads to conclusions about the nature of the Designer quite different from those of omniscience, omnipotence, and benevolence that Paley had inferred as the attributes of the Creator that Christian theology predicates of God. It is not only that organisms and their parts are less than perfect, but also that deficiencies and dysfunctions are pervasive, evidencing incompetent rather than intelligent design. Consider the human jaw. We have too many teeth for the jaw’s size, so that wisdom teeth need to be removed and orthodontists can make a decent living straightening the other teeth. Would we want to blame God for this blunder? A human engineer would have done better.

Evolution gives a good account of this imperfection. Brain size increased over time in our ancestors; the remodeling of the skull to fit the larger brain entailed a reduction of the jaw so that the head of the newborn would not be too large to pass through the mother’s birth canal. Evolution responds to the organisms’ needs through natural selection, not by optimal design but by tinkering—slowly modifying existing structures. Evolution achieves design as a consequence of natural selection while promoting adaptation. Evolution’s ID is imperfect design, not intelligent design.

Consider the birth canal of women, much too narrow for easy passage of the infant's head, so that thousands upon thousands of babies and many mothers die during delivery. Surely we do not want to blame God for this dysfunctional design or for the childrens' deaths. Science makes it understandable, a consequence of the evolutionary enlargement of our brain. Other female primates do not experience this difficulty. Theologians in the past struggled with the issue of dysfunction because they thought it had to be attributed to God's design. Science, much to the relief of theologians, provides an explanation that convincingly attributes defects, deformities, and dysfunctions to natural causes.

Another human example: why are our arms and legs, which are used for such different functions, made of the same materials—bones, muscles, and nerves—and arranged in the same overall pattern? Evolution makes sense of the anomaly. Our remote ancestors' forelimbs were legs. After our hominid ancestors became bipedal and started using their forelimbs for functions other than walking, the forelimbs were gradually modified but retained their original composition and arrangement. Engineers start with raw materials and a design suited for a particular purpose; evolution can only modify what is already there. An engineer who designs cars and airplanes, or wings and wheels, using the same materials arranged in a similar pattern, would surely be fired.

More disturbing yet for ID proponents has to be the following consideration. About twenty percent of all recognized human pregnancies end in miscarriage during the first two months of pregnancy. This misfortune amounts, at present, to more than twenty million spontaneous abortions worldwide every year. Do we want to blame God for the deficiencies in the pregnancy process? Is God the greatest abortionist of all? Most of us might rather attribute this monumental mishap to the clumsy ways of the evolutionary process than to the incompetence of an intelligent designer.

Examples of deficiencies and dysfunctions in all sorts of organisms can be listed endlessly, reflecting the opportunistic, tinkerer-like character of natural selection, which achieves imperfect, rather than intelligent, design. The world of organisms also abounds in characteristics that might be called oddities as well as those that have been characterized as cruelties, an apposite qualifier if the cruel behaviors were designed outcomes of a being holding onto human or higher standards of morality. However, the cruelties of biological nature are only metaphoric cruelties when applied to the outcomes of natural selection.

Examples of cruelty involve not only the familiar predators tearing apart their prey (say, a small monkey held alive by a chimpanzee biting large flesh morsels from the screaming monkey) or parasites destroying the functional organs of their hosts but also, and very abundantly, between organisms of the same species, even between mates. A well-known example is the female praying mantis that devours the male after coitus is completed. Less familiar is that, if she gets the opportunity, the female will eat the head of the male before mating, which thrashes the headless male into spasms of sexual frenzy that allow the female to connect his genitalia with hers. In some midges (tiny flies), the female captures the male as if he were any other prey, and with the tip of her proboscis she injects into him her spittle, which starts digesting the male's innards, which are then sucked by the female; partly protected from digestion are the relatively intact male organs that break off inside the female and fertilize her. Male cannibalism by their female mates is known in dozens of species, particularly spiders and scorpions. The world of life abounds in cruel behaviors: numerous predators eat their prey alive; parasites destroy their living hosts from within; and, as noted, females of many species of spiders and insects devour their mates.

In a letter to Joseph Hooker, Darwin rued: "What a book a Devil's Chaplain might write on the clumsy, wasteful, blundering low & horridly cruel works of nature." Darwin repeatedly returned to this theme, particularly in his extensive correspondence with the American biologist Asa Gray. In 1860, he wrote to Gray that "I cannot persuade myself that a beneficient God would have designedly created the *Ichneumonidae* with the express intention of their feeding within the living bodies of caterpillars, or that a cat should play with mice."

The design of organisms is often so dysfunctional, odd, and cruel that it possibly might be attributed to the gods of the ancient Greeks, Romans, and Egyptians, who fought with one another, made blunders, and were clumsy in their endeavors. For a modern biologist who knows about the world of life, the design of organisms is not compatible with special action by the omniscient and omnipotent God of Judaism, Christianity, and Islam. The American philosopher David Hull has made the same point with shrill language:

> What kind of God can one infer from the sort of phenomena epitomized by the species on Darwin's Galápagos Islands? The evolutionary process is rife with happenstance, contingency, incredible waste, death, pain and horror [...]. Whatever the God implied by evolutionary theory and the data of natural selection may be like, he is not the Protestant God of waste not, want not. He is also not the loving God who cares about his productions. He is not even the awful God pictured in the Book of Job. The God of the Galápagos is careless, wasteful, indifferent, almost diabolical. He is certainly not the sort of God to whom anyone would be inclined to pray.

The God of love and mercy could not have planned all this.

Evolution makes it possible to attribute these mishaps to natural processes rather than attributing them to the direct creation or specific design of the Creator. The response of some critics is that the process of evolution by natural selection does not discharge God's responsibility for the dysfunctions, cruelties, and sadism of the living world, because for people of faith God is the Creator of the universe and thus would be accountable for its consequences, direct or indirect, immediate or mediated. If God is omnipotent, the argument would say, He could have created a world where such things as cruelty, parasitism, and human miscarriages would not occur.

One possible explanation goes along the following lines of reasoning. Consider, first, human beings, who perpetrate all sorts of misdeeds and sins, even perjury, adultery, and murder. People of faith believe that each human being is a creation of God, but this does not entail that God is responsible for human crimes and misdemeanors. Sin is a consequence of free will; the flip side of sin is virtue. The critics might say that this account does not excuse God, because God could have created humans without free will (whatever these "humans" may have been called and been like). But one could reasonably argue that "humans" without free will would be a very different kind of creature, a being much less interesting and creative than humans are. Robots are not a good replacement for humans; robots do not perform virtuous deeds.

This line of argument can be extended to catastrophes and other events of the physical world and to the dysfunctions of organisms and the harms caused to them by other organisms and environmental mishaps. However, some authors do not find this extension fully satisfactory as an explanation that would exonerate God from moral responsibility. The point made again is that the world was created by God, so God is ultimately responsible. God could have created a world without parasites or dysfunctionalities. But a world of life with evolution is much more exciting; it is a creative world where new species arise, complex ecosystems come about, and humans have evolved. I am suggestion that these considerations may provide the beginning of an explanation for many people of faith as well as for theologians.

The Anglican theologian Keith Ward has stated the case in even stronger terms, arguing that the creation of a world without suffering and moral evil is not an option even for God: "Could [God] not actualize a world wherein suffering is not a possibility? He could not, if any world complex and diverse enough to include rational and moral agents must necessarily include the possibility of suffering [...]. A world with the sorts of success and happiness in it that we occasionally experience is a world that necessarily contains the possibility of failure and misery" (79-80). I am not a theologian, nor am I trying to write as one. Rather, I am writing as a scientist concerned with the theological implications of science. Thus I have repeatedly asserted, using one or another form of expression, that the evolutionary account of biological "evil" may provide a consideration for theologians to take into account or, as I have written above, "suggest a possible theological explanation of [...the] common mishaps of the living world that might be judged as evil." Thus I welcome the elaborations of experts such as, for example, Ward or Robert J. Russell, who goes even further in making the case why there should be natural (physical and biological) evil in the world, "including the pain, suffering, disease, death, and extinction that characterize the evolution of life."

An additional point which seems often to have been missed is that physical or biological (other than human) events that cause harm are not moral evil actions, because they are not caused by moral agents but are the result of natural processes. If a terrorist blows up a bus full of school children, that is moral evil. If an earthquake kills several thousand people in China, destroying their homes and livelihoods, there is no subject morally responsible because the event was not committed by a moral agent; rather, it is the result of a natural process. If a mugger uses a vicious dog to brutalize a person, the mugger is morally responsible. My wife and I often walk in the ecological preserve that borders our home in Irvine. There, we occasionally see coyotes. If a coyote were to attack us (an unlikely event, since they move away from us when we walk in their direction unless they are a pair with juveniles, in which case they typically will stand their ground), there is no moral evil that needs to be accounted for, even if one of us were severely mangled. That is, I am making the claim that in the world of nature, physical and biological (again, excluding human deeds), no morality is involved. This claim, of course, may or may not satisfy all theologians and people of faith, but I believe it deserves to be explored in itself.

Darwin, Evolution, and Design

Darwin occupies an exalted place in the history of Western thought, deservedly receiving credit for the theory of evolution. In *Origin*, he laid out the evidence demonstrating the evolution of organisms. However, Darwin accomplished something much more important for intellectual history than demonstrating evolution. *Origin* is, first and foremost, a sustained effort to solve the problem of how to account scientifically for the design of organisms. Darwin seeks to explain this design as well as the organisms' complexity, diversity, and marvelous contrivances, as the result of natural processes.

Darwin brings about the evidence for evolution because evolution is a necessary consequence of his theory of design.

There is a version of the history of the ideas that sees a parallel between the Copernican and the Darwinian revolutions. In this view, the Copernican revolution consisted of displacing the Earth from its previously accepted locus as the center of the universe, moving it to a subordinate place as just one more planet revolving around the sun. In a congruous manner, the Darwinian revolution is viewed as consisting of the displacement of humans from their exalted position as the center of life on earth, with all other species created for the service of humankind. According to this version of intellectual history, Copernicus had accomplished his revolution with the heliocentric theory of the solar system. Darwin's achievement emerged from his theory of organic evolution.

What this version says is correct but inadequate, because it misses what is most important about these two intellectual revolutions: namely, that they ushered in the beginning of science in the modern sense of the word. These two revolutions may jointly be seen as the one Scientific Revolution with two stages: Copernican and Darwinian.

The Copernican revolution was launched with the publication in 1543—the year of Copernicus' death—of his *De Revolutionibus Orbium Celestium* (*On the Revolutions of the Celestial Spheres*) and bloomed with the 1678 publication of Newton's *Philosophiae Naturalis Principia Mathematica* (*The Mathematical Principles of Natural Philosophy*). The discoveries by Copernicus, Kepler, Galileo, Newton, and others in the sixteenth and seventeenth centuries had gradually ushered in a conception of the universe as matter in motion governed by natural laws. It was shown that Earth is not the center of the universe but a small planet rotating around an average star; that the universe is immense in space and time; and that the motions of the planets around the sun can be explained by the same simple laws that account for the motion of physical objects on our planet.

These and other discoveries greatly expanded human knowledge. The conceptual revolution they brought about was more fundamental yet: a commitment to the postulate that the universe obeys imminent laws that account for natural phenomena. The workings of the universe were brought into the realm of science: explanation through natural laws. All physical phenomena could be accounted for as long as the causes were adequately known.

The advances of physical science brought about by the Copernican revolution had driven mankind's conception of the universe to a split-personality state of affairs, which persisted well into the mid-ninteenth century. Scientific explanations, derived from natural laws, dominated the world of non-living matter, on Earth as well as in the heavens. However, supernatural explanations, which depended on the unfathomable deeds of the Creator, were accepted as explanations of the origin and configuration of living creatures. Authors such as William Paley argued that the complex design of organisms could not have come about by chance, or by the mechanical laws of physics, chemistry, and astronomy, but was rather accomplished by an omniscient and omnipotent Deity, just as the complexity of a watch, designed to tell time, was accomplished by an intelligent watchmaker.

It was Darwin's genius to resolve this conceptual schizophrenia. Darwin completed the Copernican revolution by drawing out for biology the notion of nature as a lawful system of matter in motion that human reason can explain without recourse to supernatural agencies.

The conundrum faced by Darwin can hardly be overestimated. The strength of the argument from design to demonstrate the role of the Creator had been forcefully set forth by philosophers and theologians. Wherever there is function or design, we look for its author. It was Darwin's greatest accomplishment to show that the complex organization and functionality of living beings can be explained as the result of a natural process natural selection—without any need to resort to a Creator or other external agent. The origin and adaptations of organisms in their profusion and wondrous variations were thus brought into the realm of science.

Darwin's focus in *Origin* was the explanation of design, with evolution playing the subsidiary role of supporting evidence. Organisms exhibit complex design; but it is not "irreducible complexity," emerging all of a sudden in full bloom. Rather, according to Darwin's theory of natural selection, the design has arisen gradually and cumulatively, step by step, promoted by the reproductive success of individuals with incrementally more adaptive elaborations. Darwin dedicates most of *Origin* (chapters I-VIII and XIV) to natural selection, explaining how it works and considering apparent difficulties, counterexamples, and objections.

It follows from Darwin's explanation of design that evolution must necessarily occur as a consequence of organisms becoming adapted to different environments in different localities, as well as to the ever-changing conditions of the environment over time, and as hereditary variations become available at a particular time that improve, in that place and at that time, the organisms' chances of survival and reproduction. *Origin*'s evidence for biological evolution (chapters IX-XIII) is central to Darwin's explanation of design, because this explanation implies that biological evolution occurs, which Darwin therefore seeks to demonstrate in most of the remainder of the book.

Darwin and other nineteenth-century biologists found compelling evidence for biological evolution in the comparative study of living organisms, in their geographical distribution, and in the fossil remains of extinct organisms. Since Darwin's time, the evidence from these sources has become stronger and more comprehensive, while biological disciplines that emerged more recently—genetics, biochemistry, ecology, animal behavior (ethology), neurobiology, and especially molecular biology—have supplied powerful additional evidence and detailed confirmation.

Darwin surely would have been pleased by the enormous accumulation of paleontological evidence, including the discovery of fossils of organisms intermediate between major groups, such as *Archaeopteryx*, intermediate between reptiles (dinosaurs) and birds, and *Tiktaalik*, intermediate between fish and tetrapods, and the numerous fossils and diverse species of hominids, intermediate between apes and *Homo sapiens*. But there are good reasons to believe that Darwin would have been most pleased and impressed with the overwhelming evidence for evolution and precise information about evolutionary history provided by molecular biology, a source of evidence and document of history that Darwin could not even have imagined.

Molecular biology, a discipline that emerged in the second half of the twentieth century—nearly one hundred years after the publication of *Origin*—undoubtedly provides the strongest evidence yet of the evolution of organisms. Molecular biology proves evolution in two ways: first, by showing the unity of life in the nature of DNA and the workings of organisms at the level of enzymes and other protein molecules; second, and most important, by making it possible to reconstruct evolutionary relationships that were previously unknown and to confirm, refine, and time all evolutionary relationships from the universal common ancestor up to all living organisms. The precision with which these events can be reconstructed is one reason why the evidence from molecular biology is so useful and compelling to evolutionists.

DNA and proteins have been called "informational macromolecules" because they are long linear molecules made up of sequences of units—nucleotides or amino acids—that embody evolutionary information. Comparing the sequence of the components in two macromolecules establishes how many units are different. Because evolution usually occurs by changing one unit at a time, the number of differences is an indication of the recency of common ancestry. Thus, the inferences from paleontology, biogeography, comparative anatomy, and other disciplines that study evolutionary history can be tested in molecular studies of DNA and proteins by examining the sequences of nucleotides and amino acids. The authority of this kind of test is overwhelming: each of the thousands of genes and thousands of proteins contained in an organism provides an independent test of that organism's evolutionary history.

It is now possible to make an assertion that would have delighted Darwin and would surely shock creationists and other anti-evolutionists, and perhaps startle many scientists and most of the general public: gaps in knowledge of the evolutionary history of living organisms no longer need exist. Molecular biology has made it possible to reconstruct the "universal tree of life," the continuity of succession from the original forms of life, ancestral to all living things, to every species now living on Earth. The main branches of the tree of life have been reconstructed on the whole and in great detail. More details about more and more branches of the universal tree of life are published in scores of scientific articles every month. The virtually unlimited evolutionary information encoded in the DNA sequence of living organisms allows evolutionists to reconstruct all evolutionary relationships leading to present-day organisms, with as much detail as is wanted. Invest the necessary resources (time and laboratory expenses) and one can have the answer to any query, with as much precision as is desired.

Coda

It may be fitting to conclude with a statement from Pope John Paul II in his address of October 22, 1996 to the Pontifical Academy of Sciences:

> New scientific knowledge has led us to realize that the theory of evolution is no longer a mere hypothesis. It is indeed remarkable that this theory has been progressively accepted by researchers, following a series of discoveries in various fields of knowledge. The convergence, neither sought nor fabricated, of the results of work that was conducted independently is in itself a significant argument in favor of this theory.

And with a 1998 statement from the Protestant theologian Sir Arthur Peacocke in "Biological Evolution—A Positive Appraisal":

> What I find even more surprising, and less understandable, is the way in which the "disguised friend" of Darwinism, and more generally of evolutionary ideas, has been admitted (if at all) only grudgingly [...] into the parlors of Christian theology. I believe it is vital for this churlishness to be rectified [...] if the Christian religion (indeed any religion) is to be believable and have intellectual integrity.

Works Cited

Aquinas, T. "Of God and His Creatures." *Summa Contra Gentiles*. Ed. J. Rickaby. London: Burns and Oates, 1905. 241-368.

---. "Existence and Nature of God." *Summa Theologiae*. Ed. Blackfriars. New York: McGraw-Hill, 1964. 10-249.

Arp, R. "The *Quinque Via* of Thomas Hobbes." *History of Philosophy Quarterly* 16. 367-394.

Augustine. *The City of God*. Ed. R. Dyson. Cambridge, UK: Cambridge University Press, 1998.

Behe, M. *Darwin's Black Box: The Biochemical Challenge to Evolution*. New York: Free Press, 1996.

Bell, C. *The Hand, Its Mechanisms and Vital Endowments As Evincing Design*. Whitefish, MT: Kessinger Publishing, LLC, 1833.

Darwin, C. *On the Origin of Species By Means of Natural Selection*. London: John Murray, 1859.

Hooke, R. *Micrographia, or, Some Physiological Descriptions of Minute Bodies Made By Magnifying Glass with Observations and Inquiries Thereupon*. London: Martyn and Allestry, 1665.

Haught, J.F. "Darwin's Gift to Theology." *Evolutionary and Molecular Biology: Scientific Perspectives on Divine Action*. Ed. Russell, et al. Vatican City State: Vatican Observatory Press/Berkeley, CA: Center for Theology and the Natural Sciences, 1998. 393-418.

Hume, D. *Dialogues Concerning Natural Religion*. Ed. N.K. Smith. Oxford: Oxford University Press, 1935. 244.

Klocker, H. *God and the Empiricists*. New York: The Bruce Publishing Company, 1968.

More, H. "An Antidote Against Atheism." *A Collection of Several Philosophical Writings of Dr. Henry More*. London: Flesher and Morden, 1662.

Nieuwentijdt, B. *The Religious Philosopher, or the Right Use of Contemplating the Works of the Creator in the Most Amazing Structure of the Heavens with All Their Furniture*. Trans. J. Chamberlayne. Whitefish, MT: Kessinger Publishing, LLC, 2007.

Paley, W. *Natural Theology, or Evidences of the Existence and Attributes of the Deity Collected from the Appearances of Nature*. New York: American Tract Society, 1802.

Peacocke, A.R. "Biological Evolution: A Positive Appraisal." *Evolutionary and Molecular Biology: Scientific Perspectives on Divine Action*. Ed. Russell, et al. Vatican City State: Vatican Observatory Press/Berkeley, CA: Center for Theology and Natural Sciences, 1998. 357.

Plato. *Timaeus*. *Plato: Complete Works*. Ed. J. Cooper. Indianapolis: Hackett Publishing Company, 1997.

Ray, J. *The Wisdom of God Manifested in the Works of Creation*. London: Wernerian Club, 1691.

Russell, R.J. "Physics, Cosmology, and the Challenge to Conequentialist Natural Theology." *Physics and Cosmology: Scientific Persepectives on the Problem of Natural Evil*. Ed. N. Murphey, et al.Vatican City State: Vatican Observatory Press/Berkeley, CA: Center for Theology and the Natural Sciences, 2007.

Swinburne, R. *The Christian God*. Oxford: Oxford University Press, 1994.

Voltaire. "Voltaire, Francois-Marie Arouet de. *Encyclopedia of Philosophy*, Volume 8.. Ed. Donald Borchert. London: Macmillan, 1967. 262-270.

Ward, K. T*he Big Questions in Science and Religion*. West Conshohocken, PA: Templeton Foundation Press, 2008.

Francisco J. Ayala is University Professor and Donald Bren Professor of Biological Sciences at the University of California, Irvine. He has been a member of the US President's Committee of Advisors on Science and Technology, President and Chairman of the Board of the American Association for the Advancement of Science, and President of Sigma Xi, The Scientific Research Society of the US. In 2003 he was appointed University Professor, the highest title at the University of California and the only professor currently holding this title at the University of California, Irvine. He has been President of the Society for the Study of Evolution, a member of the Council of the US National Academy of Sciences, the National Advisory Council of the Institute of General Medical Sciences, the National Advisory Council for the Human Genome Project, the Executive Committee of the Science Advisory Board of the Environmental Protection Agency, the Commission on Life Sciences, and the Board on Basic Biology of the National Research Council.

He is a member of the US National Academy of Sciences, the American Academy of Arts and Sciences, and the American Philosophical Society, and a Fellow of the Linnean Society of London. He is a Foreign Member of the Accademia Nazionale dei Lincei, the Mexican Academy of Sciences, Royal Academy of Sciences of Spain, the Russian Academy of Sciences, the Russian Academy of Natural Sciences, the Latin American Institute for Advanced Studies, and the Serbian Academy of Sciences and Arts.

Ayala has received honorary degrees from Universities in six different countries and numerous awards, including the 2001 National Medal of Science at the White House, awarded by President George W. Bush.

He has published more than 1,000 articles and is author or editor of 40 books.

St. Andrews
UNIVERSITY